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No Uncertainty No Knowledge!

M.S. Salama

UNIVERSITY OF TWENTE, FACULTY OF GEO-INFOMATION SCIENCE AND EARTH OBSERVATION

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FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

Objective

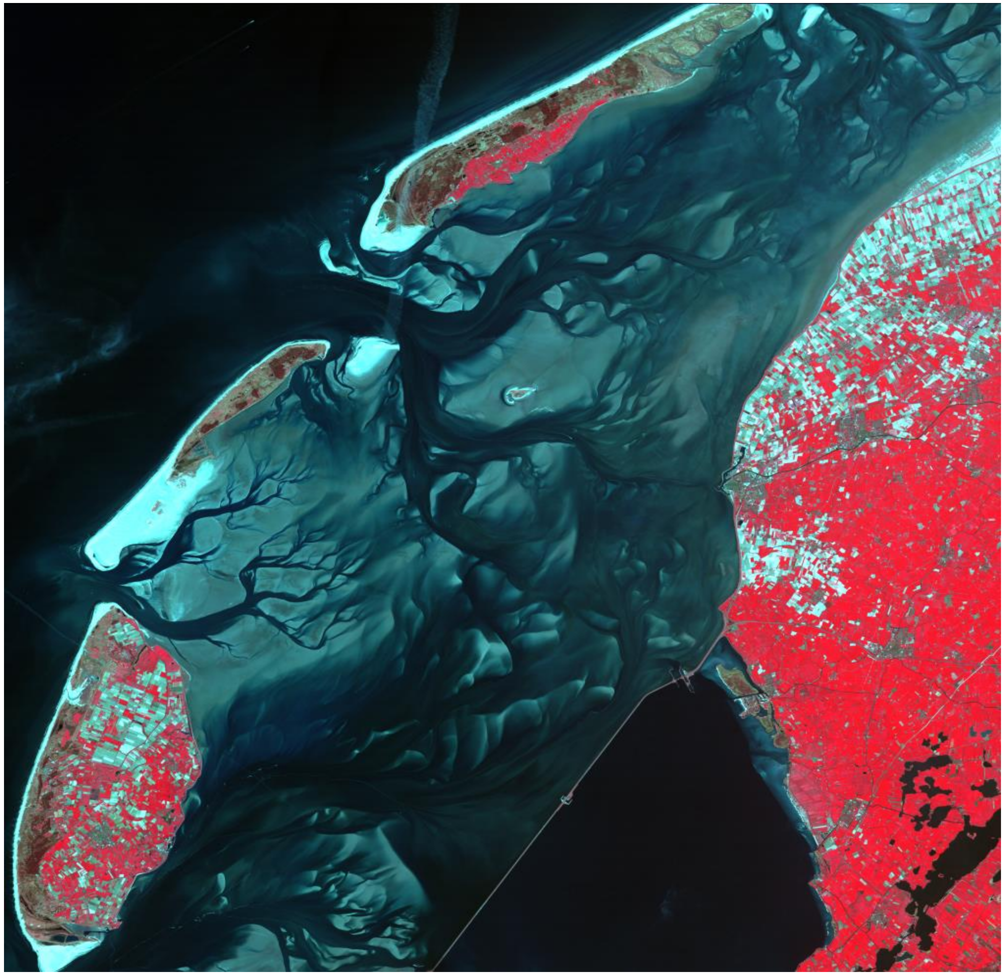
- Discus some methods to evaluate the uncertainty of derived IOP from ocean color radiometric data;
- Rise some questions for further thoughts.

Why bother about uncertainty?

The aquatic biosphere is uniquely monitored by ocean color sensors as they provide synoptic information on key biophysical and biochemical variables at high temporal frequency.

Every measurement is subject to some uncertainty.

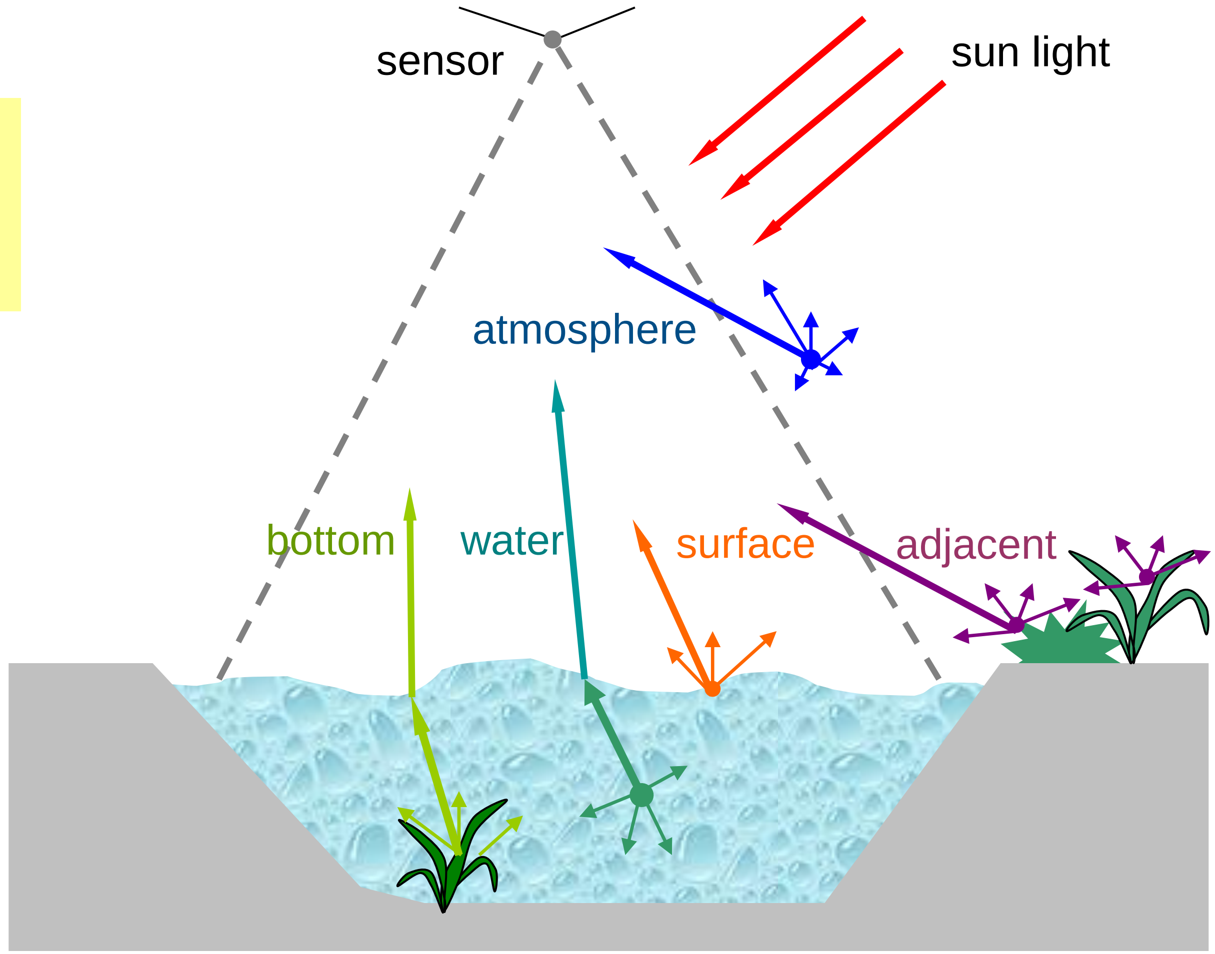
A measurement result is only complete if it is accompanied by a statement of the uncertainty in the measurement.



Challenges of ocean color measurements

The received light (radiance) at the sensor level is a combination of:

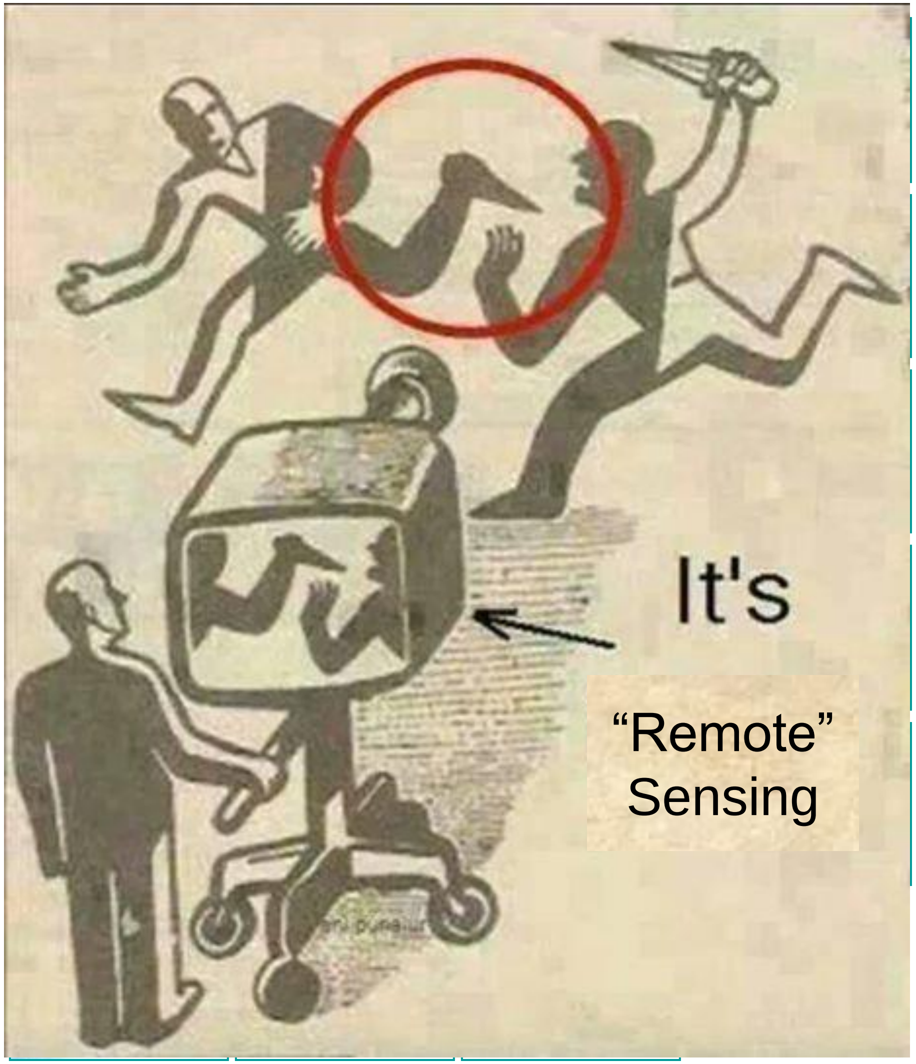
water +	max ~ 20 %
bottom + surface + adjacent + atmosphere	min ~ 80 %

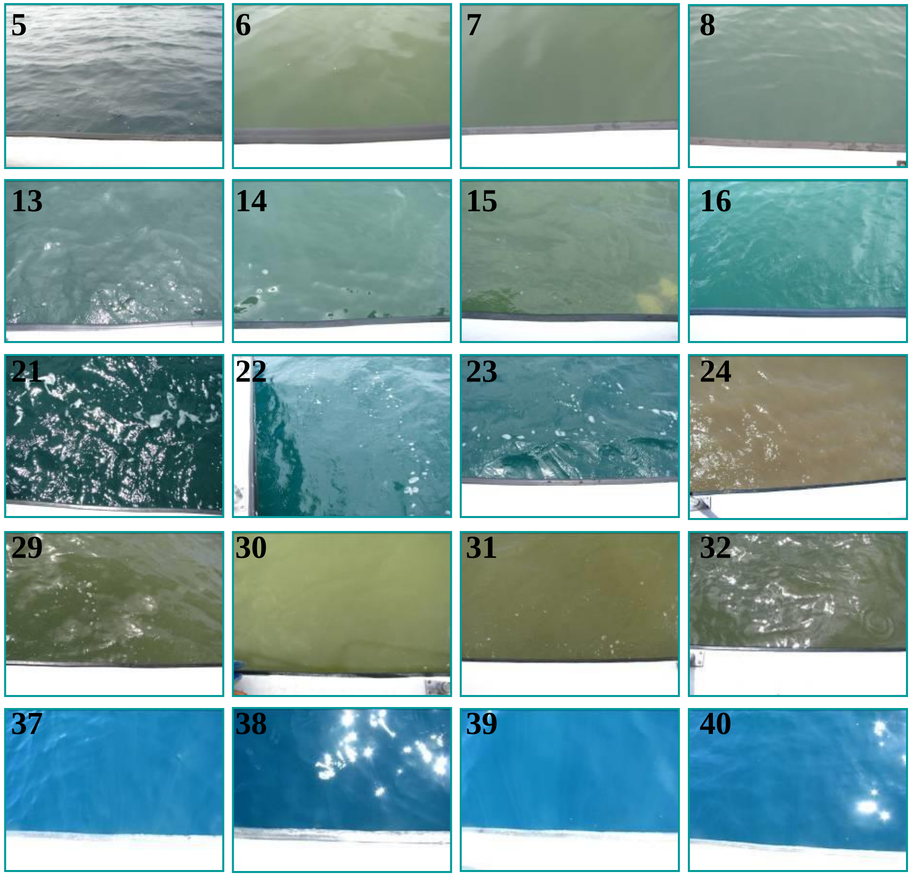


The water leaving signal is affected by suspended and dissolved materials in the water column.
It is also subjected to large uncertainty in its derivation.

Challenges of ocean color measurements

The primary measurement is the visible light leaving the water column.





What you observe is not always what it is!

Error versus uncertainty

- **Error** is the difference between observation and the true value. It measures how close a measured value is to the true value(accuracy). As true values are by nature indeterminate (GUM: B.2.3,note 2), error cannot be determined and discussed meaningfully.

- **Uncertainty** of a measured value is an interval around that value such that any repetition of the measurement will produce a new result that lies within this interval.

- **Precision** measures how closely two or more measurements agree with other.

Error (unknown) leads to uncertainty (can be quantified)

Uncertainty types

Uncertainty arises from random effects and from imperfect correction of the result for systematic effects and has therefore two types:

Random and systematic uncertainty

$$Rrs_{observed} = Rrs_{real} + \varepsilon_0 + \epsilon_s$$

?

$$Rrs_{real} = Rrs_{model} + \epsilon_m$$

Random: unpredicted variation or residuals from corrections;

Systematic: are caused by systematic effects, e.g. degradation of the sensor, bias in the model etc...

Both could be independent or dependent on λ.

But spectrally dependent random uncertainty may also leads to systematic uncertainty!

Methods for evaluating uncertainty

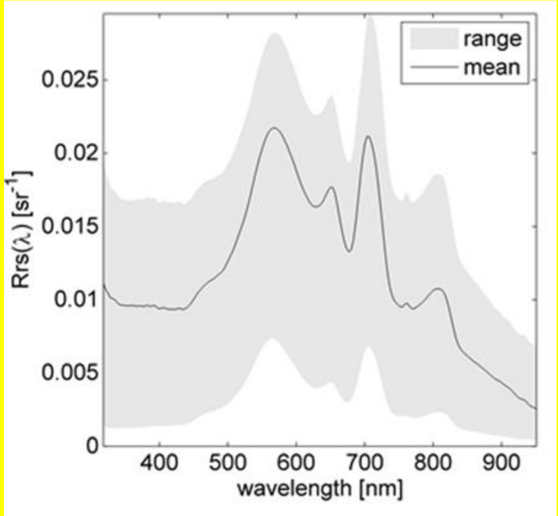
Two methods A & B for evaluating uncertainty, both are based on probability distribution function (PDF)

probability density function

Type A

PDF is derived from an observed frequency distribution (e.g. high frequency in-situ measurement). \ It should not be mixed with multi sensor observations!

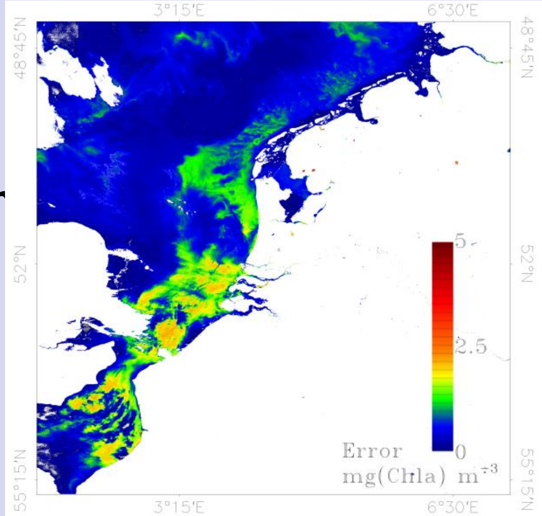
as they are a measure of precision!



Type B

PDF is assumed from known distribution (assumed): related to model-parametrization setup, provides pixel-by pixel estimates, but these are somehow biased!!!

as they are (mostly) obtained from derivatives or assumed PDF of the residuals.



Type A method

- Based on repeated measurements of a reference target with known radiance (mostly radiometric);
- This method is extensively used in **ocean color vicarious calibration**, examples:
- **Absolute calibration** using Rayleigh scattering (Fougnie et al., 2002), Sky radiance (Santer and Martiny 2003) ;
- **Inter band calibration** using sun glint (Hagolle et al., 2004), cloud (Fougnie and Bach 2009), deserts (Lacherade et al., 2013).

It is based on:

1- selecting a reference target with known surface radiance/reflectance

2- propagate it through the atmosphere using measured atmospheric parameters and /or radiative transfer

3- compare with TOA radiance and perform the calibration

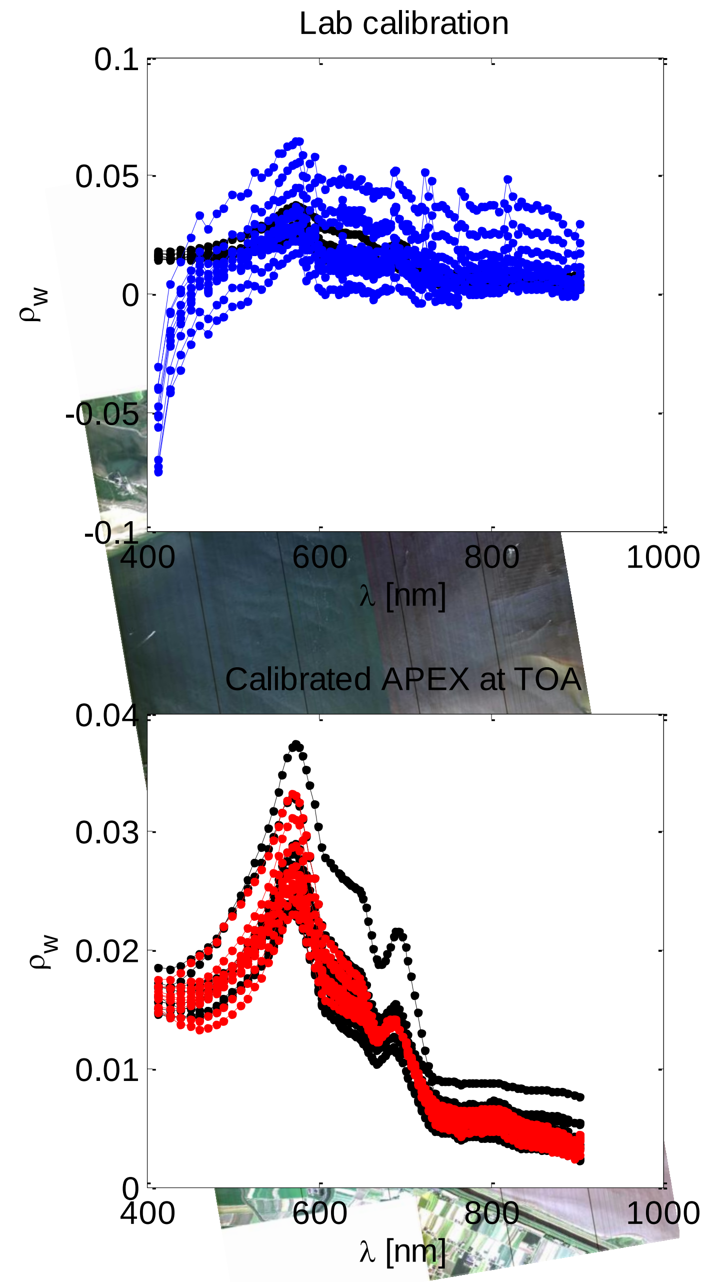
Type A method is used in ocean color for inter/ sensor calibration and is mostly radiometric

Type A: applied to APEX

- APEX (Airborne Prism Experiment) is an imaging spectrometer (400-2500 nm@288 bands and 3.5 m).

- Choose stable target (asphalt road);
- Measure it in-situ during the APEX flight;
- Compare it with different APEX flight lines;
- Perform a linear calibration.

- Please see poster nr:126



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Type B: based on model sensitivity (BMS)

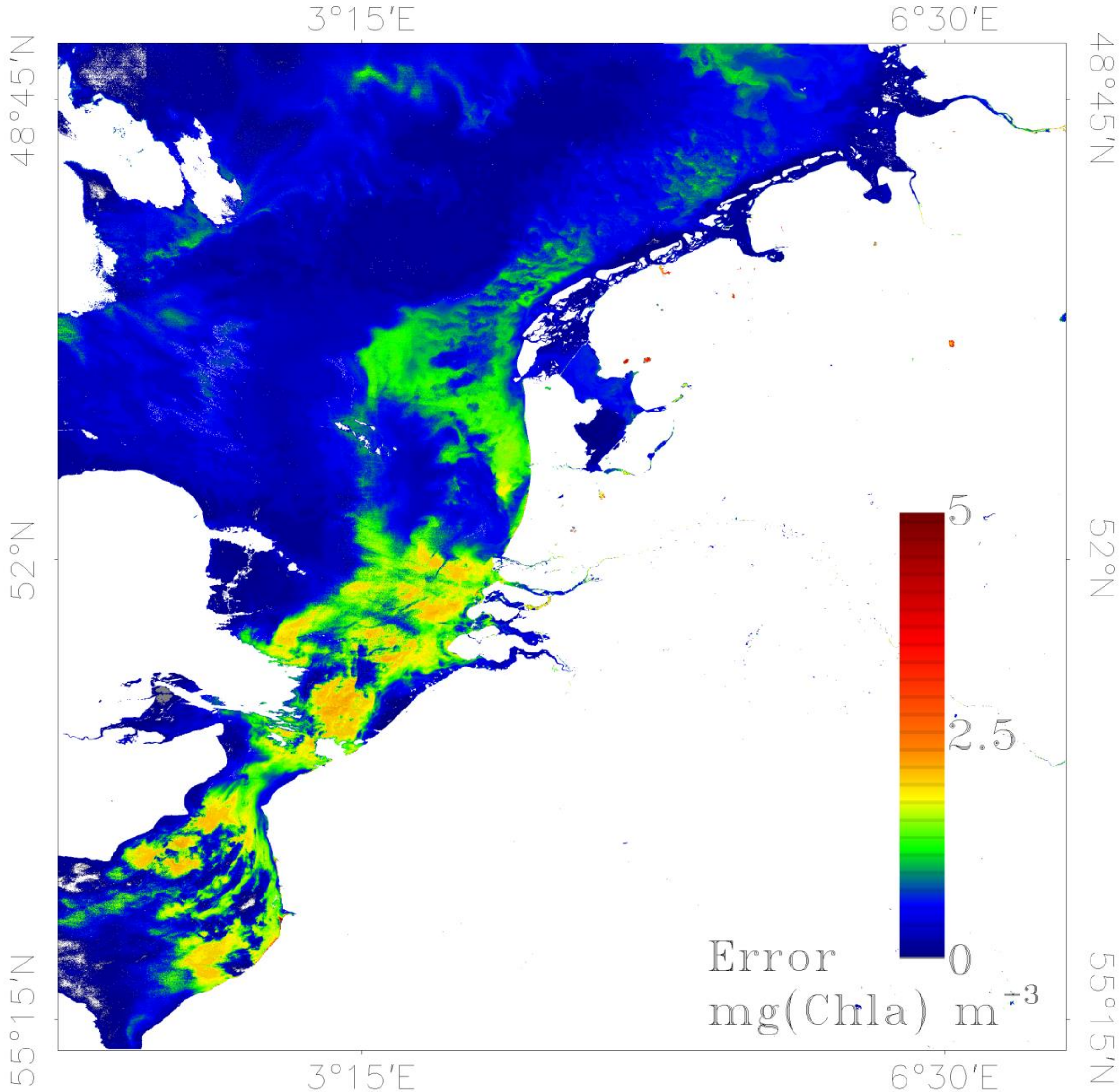
Analytical:

- Estimated form model-parametrization set up as
- $\Delta R_{rs} = \sum \frac{\delta R_{rs}}{\delta iop_i} \Delta iop_i$
- Approximated using Taylor series expansion of the second moment:
- $Var_{Rrs} = \sum w_i \times Var_i,$

$w_i = \left(\frac{\delta R_{rs}}{\delta iop_i}\right)^2$

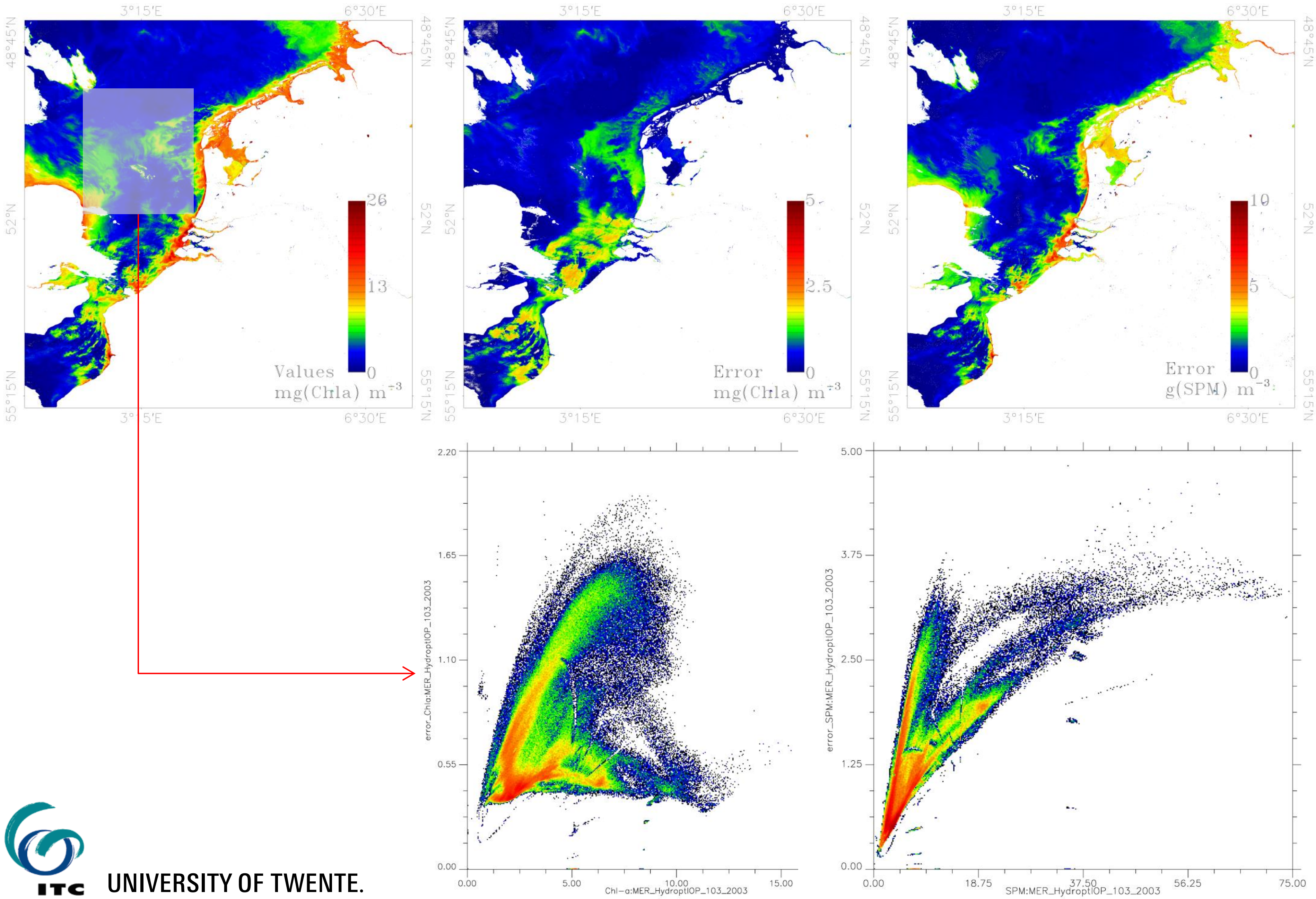
Direct

Simulate the sensitivity of the model by randomly varying model'sindependent variabels



For correlated uncertainty we should use extra terms

Correlated uncertainty in BMS



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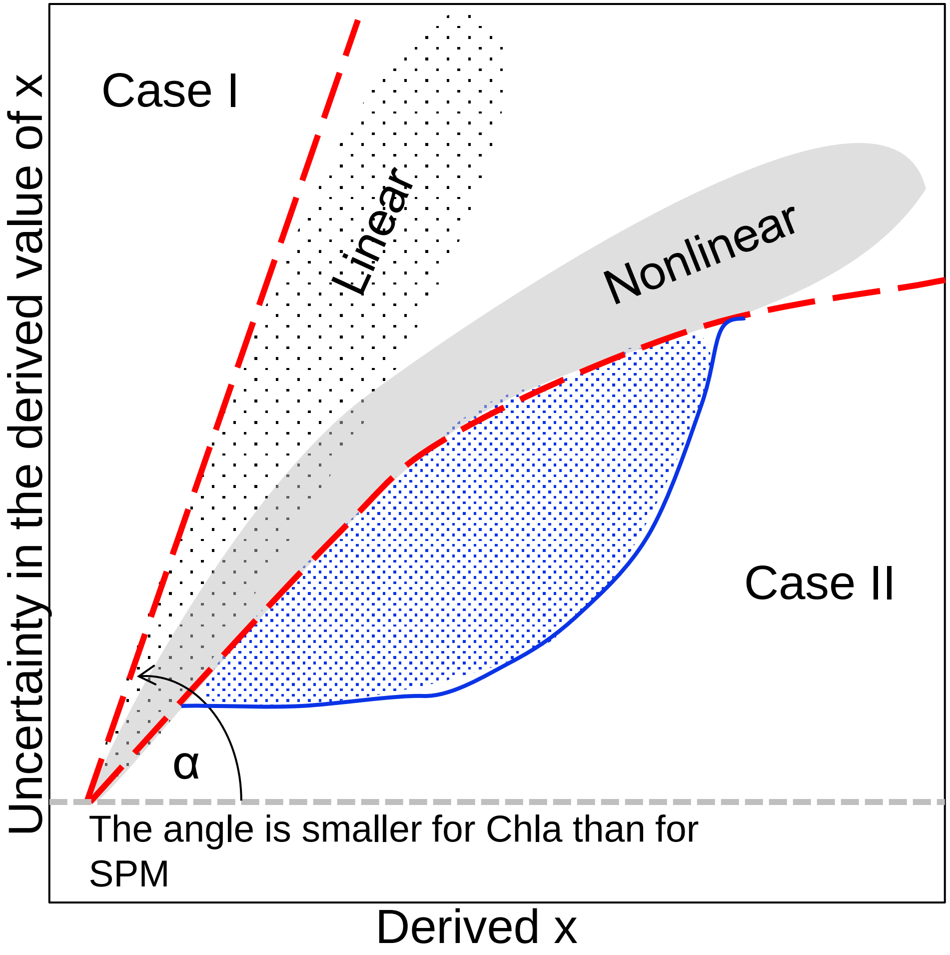
Correlated uncertainty in BMS

Ten years of MERIS images were analyzed in the north sea off the Dutch bight using Hydropt (Van der Woerd and Pasterkamp 2009) and the uncertainty model of Bates and. Watts, (1988).

In general uncertainty is correlated to the derived quantity following the general sketch.

However in turbid waters the lower “nonlinear’ curve becomes more complex: only for Chla!!!



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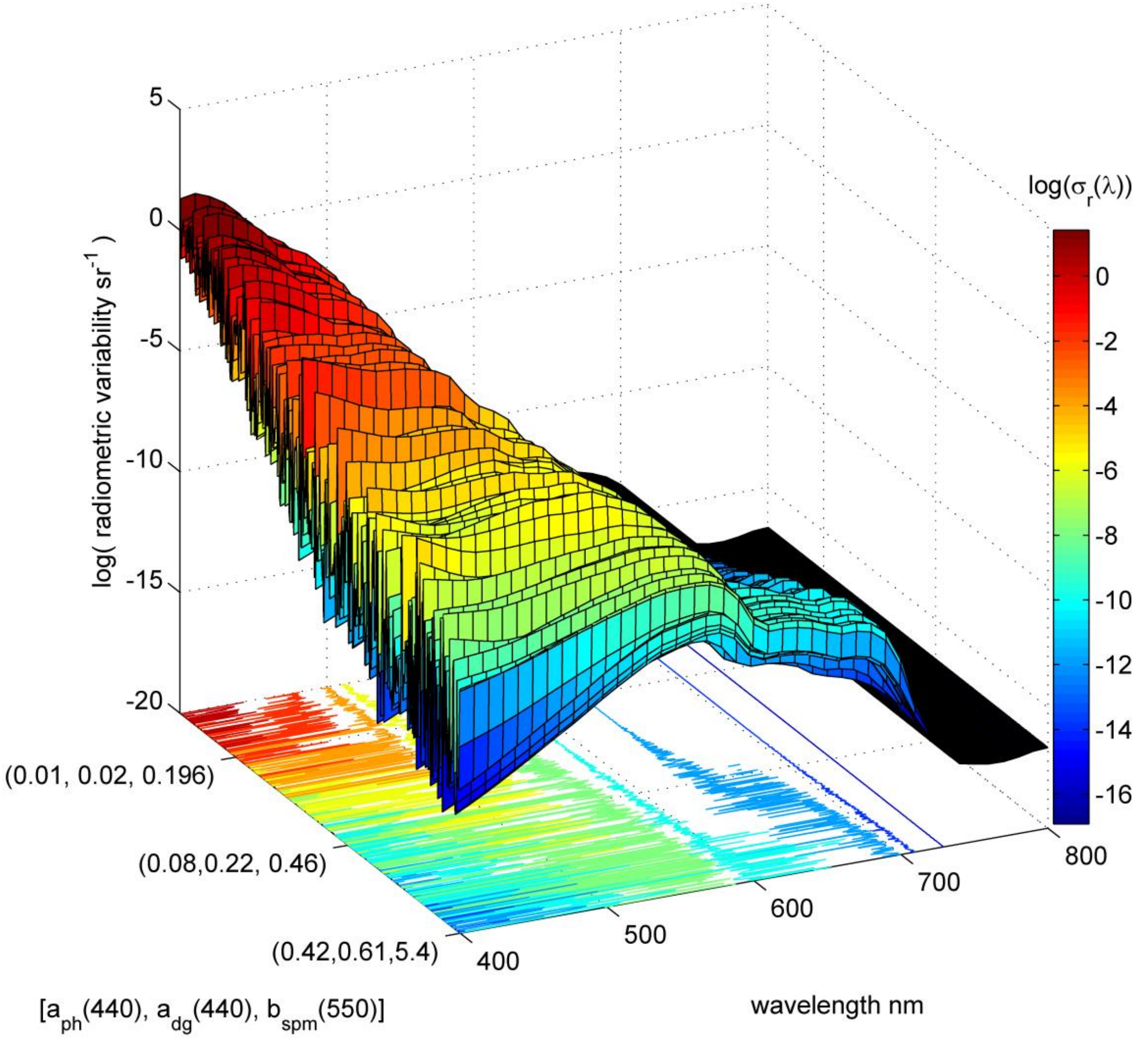
Propagation of uncertainty

$$\sigma_r{}^2 = \sum \left(\frac{\delta Rrs}{\delta iop_x}\right)^2 \times \sigma_x{}^2$$

Combined uncertainty actually measures the sensitivity of radiance to changes in IOP of a specific model-parametrization setup.



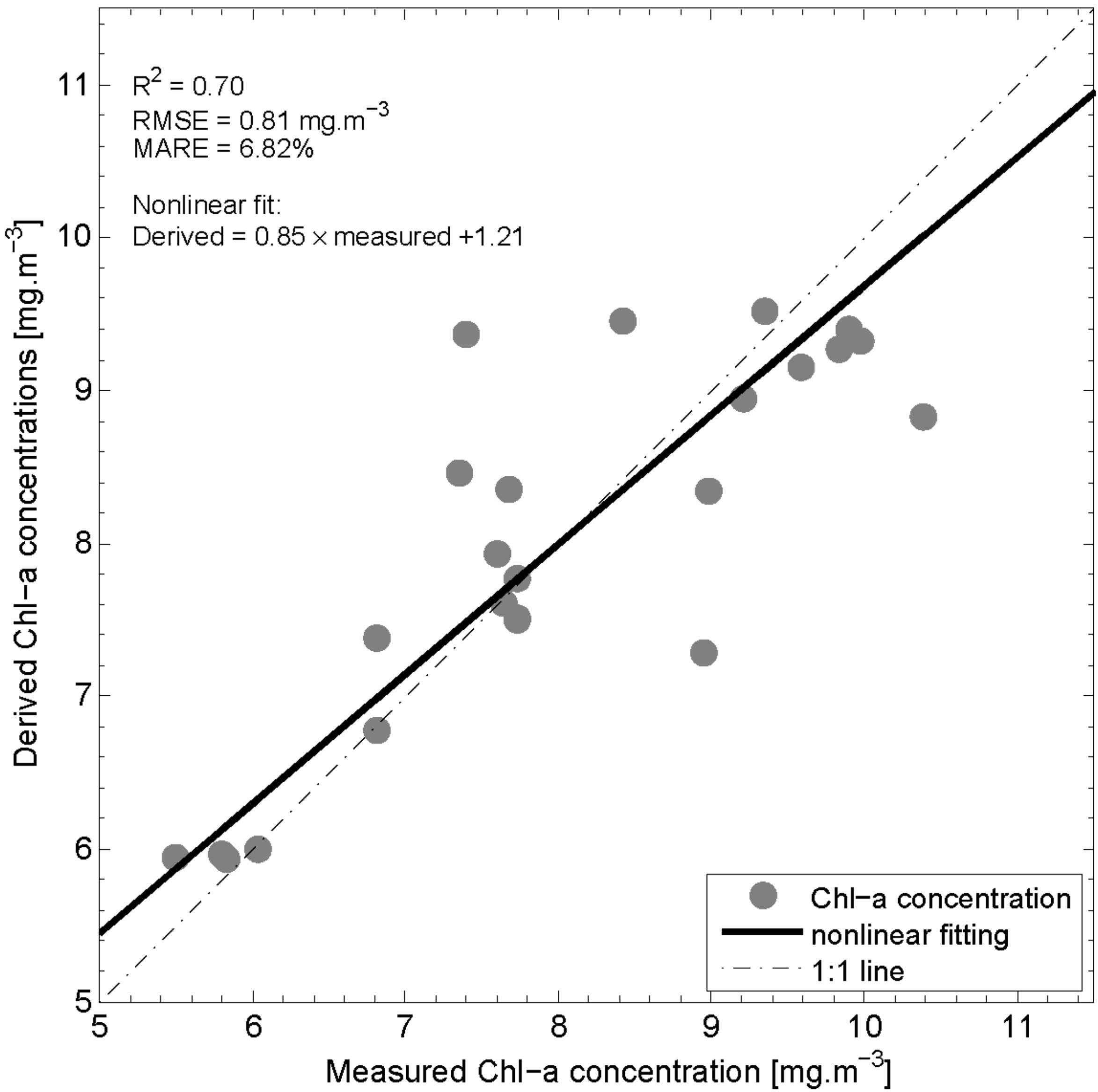
GSM (Maritorena et al., 2002) applied on IOCCG simulations (Lee et al., 2006). Only for Chla- we used different parametrization (Lee et al., 1999).

Propagation of uncertainty

$$\sigma_r{}^2 = \sum \left(\frac{\delta Rrs}{\delta iop_x}\right)^2 \times \sigma_x{}^2$$

Combined uncertainty actually measures the sensitivity of radiance to changes in IOP of a specific model-parametrization setup.

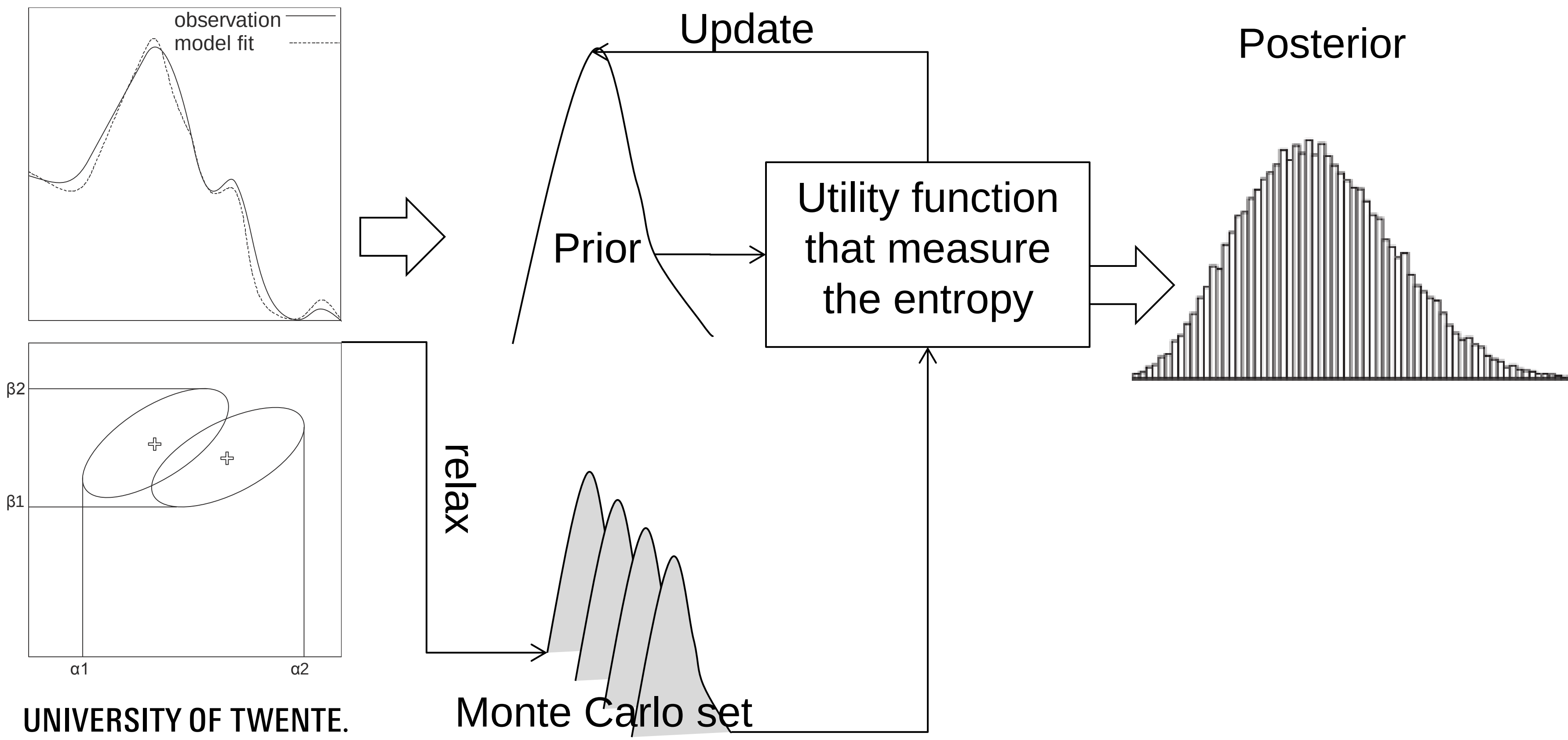
In other words, the uncertainty measure is function of the used model and parametrization setup and my not represent the actual difference between measured and derived IOP.



Type B: based on stochastic inferences (BSI)

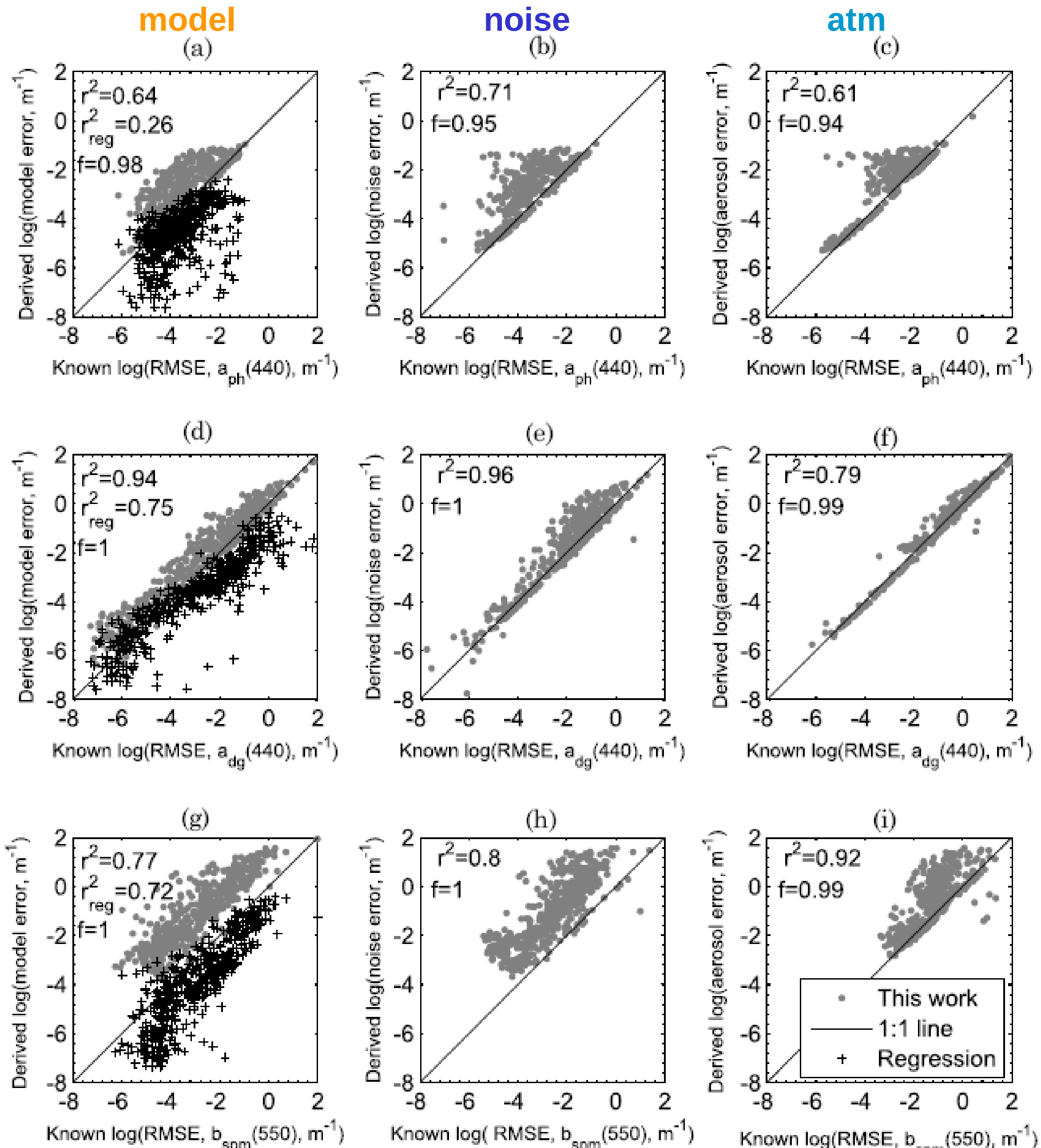
e.g. Salama and Stein 2009, propose a Bayesian updating method:

- Having a prior distribution generated from a model response (typical type BMS e.g. Wang-Boss-Roesler, 2005)
- Using Bayesian updating we try to converge to a posterior PDF that better represent uncertainty



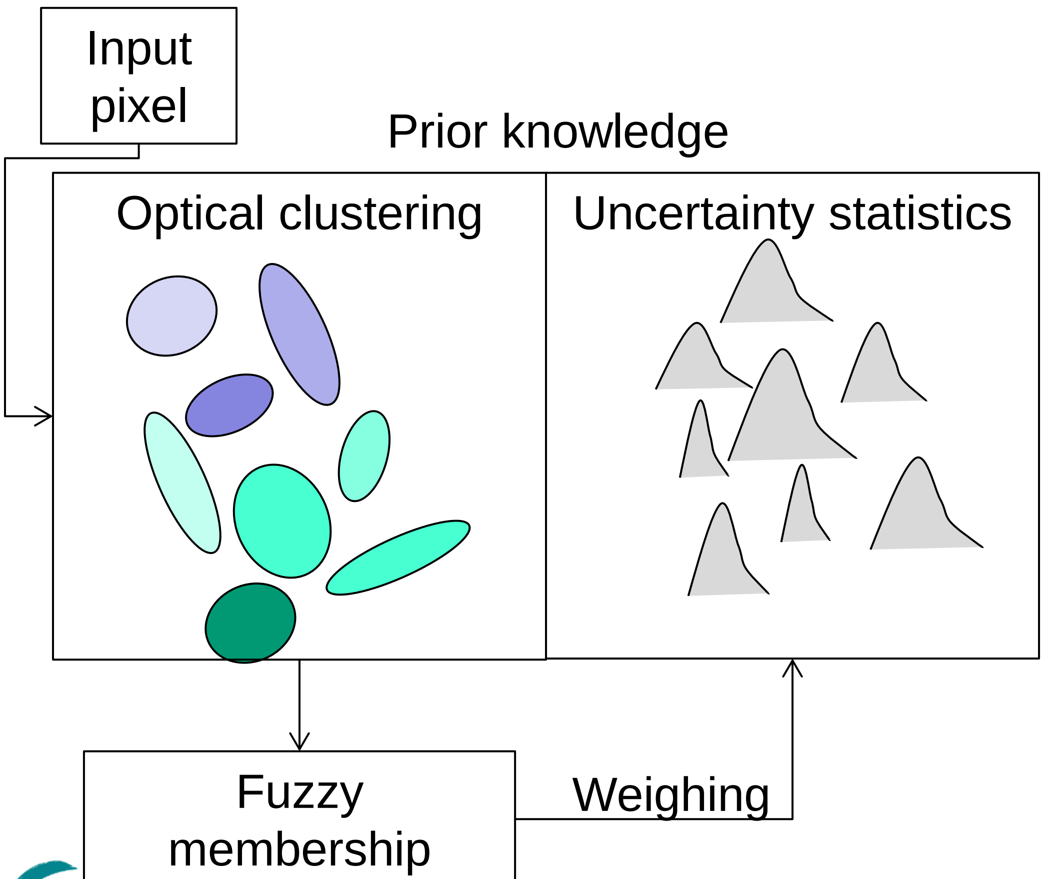
Type B: based on stochastic inferences (BSI)

- It still needs extensive testing;
- But it provides uncertainties that are independent of the model-parametrization setup (sensitivity);
- It does not require knowledge on radiometric uncertainty !

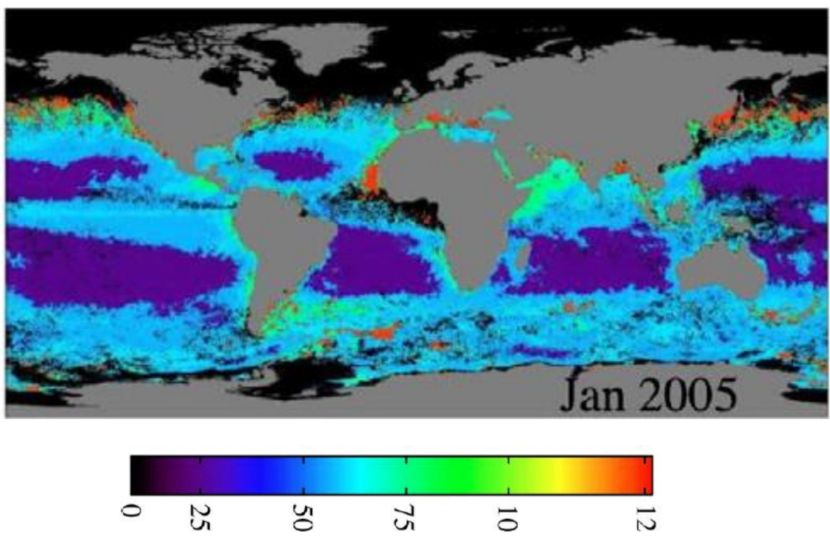


Type B: based on stochastic inferences (BSI)

The method of Moor et al.,(2009) uses optical classification to characterize the uncertainty for each water. I put it here under the BSI category as it uses fuzzy membership to weigh the uncertainty



Posterior knowledge



Summary and challenges

Guide to the expression of uncertainty in measurement (GUM) defines that the ideal method for evaluating and expressing the uncertainty of the result of a measurement should be:

- universal: the method should be applicable to all kinds of measurements and to all types of input data used in measurements.
- The actual quantity used to express uncertainty should be:

  – internally consistent: it should be directly derivable from the components that contribute to it, as well as independent of how these components are grouped and of the decomposition of the components into subcomponents;

  – transferable: it should be possible to use directly the uncertainty evaluated for one result as a component in evaluating the uncertainty of another measurement in which the first result is used
- The term “systematic uncertainty” can be misleading and should be avoided

Summary and challenges

So strictly speaking:

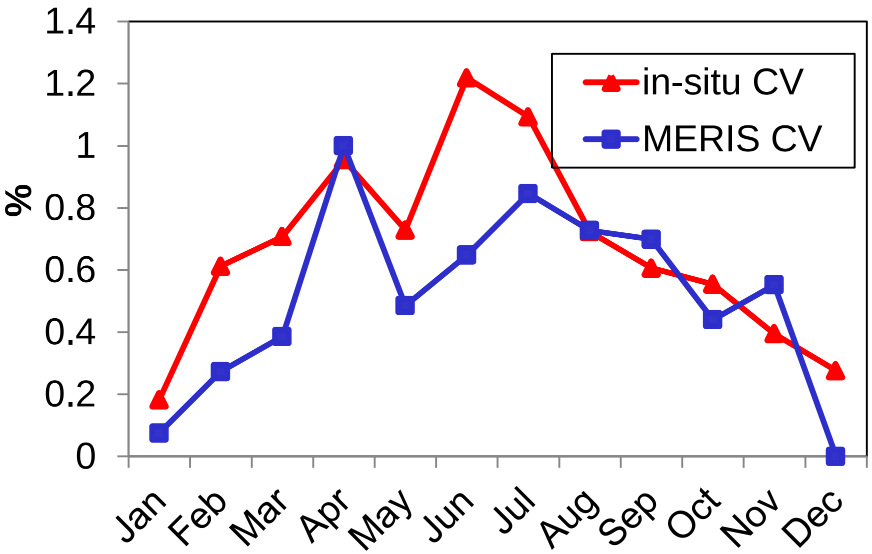
- When we compute the uncertainty using repeated measurements (Type-A): we are using it to inter/ calibrate ocean color sensors;

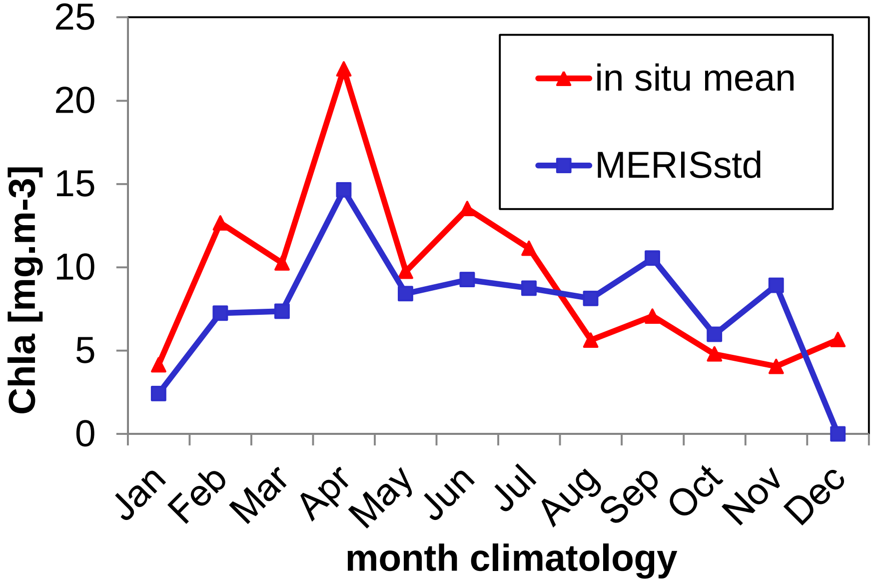
- When we compare different satellite products we are measuring the precision of these sensors, even after calibration or the use of reference sensor;

- Uncertainty propagation method (Type-BMS) requires the radiometric uncertainty. Basically we are estimating the sensitivity of used model-parametrization setup w.r.t. changes in IOPs; Moreover, error-propagation equation has no closure for the actual differences

- Quit often estimated uncertainty does not match actual differences between measured and derived IOPs..

Should we compare other values than magnitude?





Second order : MERIS versus in situ data for the ten years matchup

Comparing the
coefficient of variability: this reflects the temporal variability rather than uncertainty.

Prior knowledge is essential, it provides additional information that improve our confidence on uncertainty;

Finally : How to validate uncertainty measures?

Acknowledgement